Appendix N

ANALYSIS OF FLOODPLAIN WATER LEVELS IN RELATIONSHIP TO PROPOSED MFL CRITERIA FOR THE NORTHWEST FORK THE LOXAHATCHEE RIVER

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INTRODUCTION

The primary focus of the proposed MFL was to address the problem of saltwater intrusion within the Northwest Fork of the Loxahatchee River. During the course of this investigation, another major ecological question was identified, specifically: What are hydrologic requirements of the floodplain swamp, particularly that portion of the river designated as Wild and Scenic, and how will the implementation of the proposed MFL criteria impact or benefit that section of the river?

Two primary approaches were used to answer this question: (1) a review of the literature was conducted to identify appropriate water depths and hydroperiods that will sustain a healthy floodplain swamp community, and (2) floodplain transect data were analyzed to determine the relationship between river flow (calculated from stage data obtained from the Lainhart Dam) and the inundation characteristics of the floodplain swamp. The study area was limited to the area of the upper NW Fork of the Loxahatchee River located between Indiantown Rd. (State Rd. 706) and the Trapper Nelson's interpretive site (river mile 10.7). Areas downstream of Trapper Nelson's site were not included in this study, since the Lainhart Dam flow-floodplain stage relationships are different due to the effects of tributary inflows. The information presented below is a preliminary examination of hydroperiod requirements and inundation characteristics of major biological communities in the floodplain of the upper NW Fork of the Loxahatchee. District staff also used these relationships to assess the effects of implementing the proposed minimum flow criteria that were presented in the main body of this report.

METHODS

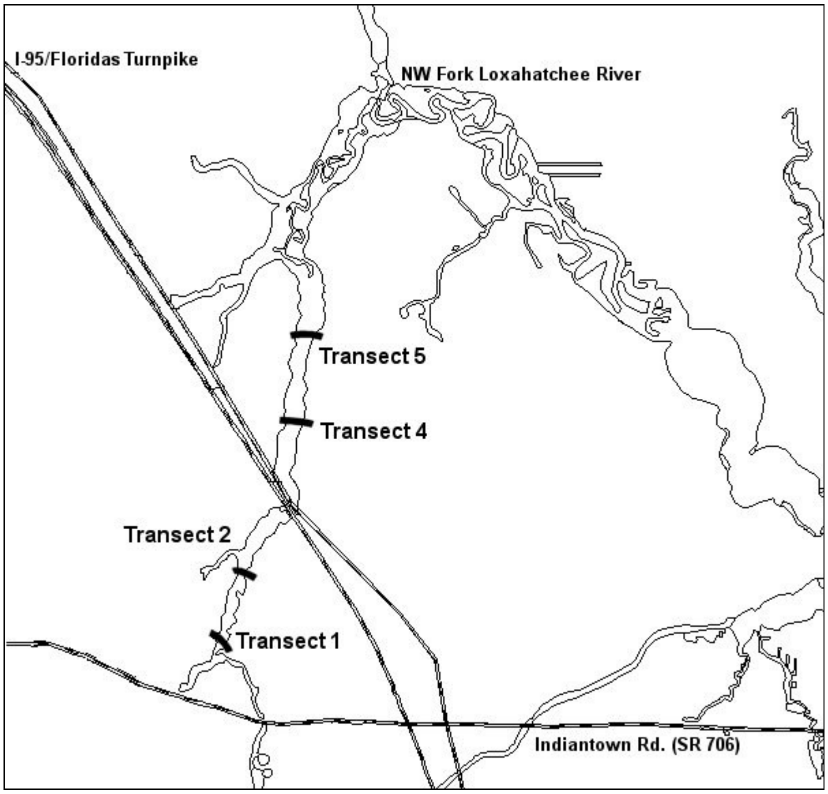
Literature Review

A literature review was conducted to identify the water depth and hydroperiod requirements of selected floodplain swamp species. This review was also used to obtain information on the germination requirements and flooding tolerances of cypress and other common floodplain swamp species. A summary of the major studies and relevant findings are provided (also see **Appendix A**).

Floodplain Transect Analysis

During the mid-1980's District staff conducted a series of floodplain surface water and soil elevation measurements at four selected transects located along the Wild and Scenic portion of the Loxahatchee River (D. Worth personal communication). Transects 1 and 2 were located between Indiantown Rd. and the Florida Turnpike/I-95 bridges (**Figure 1).** Transects 4 and 5 were located between the Florida Turnpike/I-95 bridges and the Trapper Nelson's interpretive site, located in Jonathan Dickinson State Park. Transect 3 was also surveyed, but was not included in this analysis because it lies along Cypress Creek near the confluence with the NW Fork and was outside the area of interest. Elevation measurements (feet NGVD) were made at 10-ft. intervals along each transect and were entered into a MS Excel spreadsheet (1 cell = 10 ft.). The number of cells that were at or below a specific water level were used to calculate the percent of the transect cross-sectional area that was inundated at a given stage.

Figure 1. Location of the transect sites along the upper NW Fork of the Loxahatchee River



Wells and stage recorders were installed at each of the four transect locations to measure daily average water levels (in feet NGVD). Data collected from each of the transect stage recorders were related to USGS and SFWMD stage measurements obtained from the Lainhart Dam. The four well stage recorders were in operation from 1984 through 1990 and the archived data was extracted from the SFWMD's DBHYDRO database. Additional information concerning the well sites are provided in **Table 1.**

Table 1. Floodplain Transect Well monitoring information

Transect	Survey Date*	Heading*	Gauging Station**	Lat/Long**	X-Y Coordinates (NAD 27)**	Location**
T1	12/20/83	N 22° 30' W	LOX.R1_G	26 5625.202 80 1024.15	925479.393 948362.741	Approx. 0.5 km down-stream of State Rd. 706
T2	12/22/83	S 75° E S 36° E S 11° E	LOX.R2_G	26 5656.201 80 1012.15	926544.921 951500.123	Downstream side of Masten Dam
T4	4/9/84	N 61° W	LOX.R3_G	26 5729.2 80 0958.149	927789.931 954840.688	Approx. 1.5 km down-stream of Masten Dam
T5	3/13/84	N 46° E S 85° E	LOX.R4_G	26 5806.199 80 0952.149	928308.185 958580.409	Approx. 2.5 km down-stream of Masten Dam

*Source: SFWMD survey staff field notes
**Source: SFWMD DBHYDRO database

Stage hydrographs (1984-1990) were developed from the transect well data. Summary statistics (mean, standard deviation, and range of variation) were developed from these hydrographs to calculate mean differences in elevation between each transect site as compared to the Lainhart Dam. Data used in these analyses were only from periods when concurrent and continuous stage data were available

Estimates of Floodplain Hydroperiod Length

Calculations were made to determine the average percent of time each transect site was flooded, during the period since major improvement were made to the G-92 structure in 1987. Using soil elevation data from the transect studies, the average elevation of each floodplain transect was estimated, in feet NGVD. Lainhart Dam daily stage measurements were obtained from USGS and SFWMD data obtained from the District's DBHYDRO database. The relative differences in surface water elevations were calculated between the Lainhart Dam and each transect site shown in **Table 5. A**ctual Lainhart Dam stage records from 1987-2001were then used to develop stage hydrographs and stage duration curves for each transect and determine the average percent of time each transect has been inundated (hydroperiod) since 1987.

Effects of Proposed MFL on Floodplain Inundation Characteristics

In an effort to assess the effects of the proposed MFL criteria on floodplain inundation characteristics, the following analyses were conducted. Lainhart Dam stage data (ft. NGVD) was converted into average daily flow data (cubic feet per second) using a weir equation developed by SFWMD staff (see **Appendix D**). These daily flow records were then related to measured floodplain stage data recorded at each transect. This information was used to determine the range of flows needed to inundate each floodplain transect in terms of percent of area flooded, i.e., for a given flow regime, a certain percentage of the floodplain cross sectional area is inundated. These data were used to establish the relationship between the amount of water that passes over the Lainhart Dam and the percent of each transect that is inundated at a given Lainhart Dam flow rate.

RESULTS

LITERATURE REVIEW

The primary focus of this review was to identify relevant studies that indicate hydrological conditions required for germination and seedling survival of bald cypress and other floodplain swamp species and the ranges of natural and extreme (flood and drought) water level fluctuations (hydroperiod) required to sustain a healthy floodplain swamp community dominated by bald cypress and mixed hardwood swamp communities similar to those communities found along the upper NW Fork of the Loxahatchee River. The major findings of the literature review are discussed below.

Wetland Hydroperiod Requirements

The aspects of wetland flooding can be separated into components of hydroperiod, depth, seasonality, and frequency. When considered together, these components define a wetland's hydrologic regime. Simplifying the hydrologic regime in terms of "average" annual values for depth, duration, and frequency of flooding is helpful in characterizing general conditions. In reality, however, a wetland is unlikely to experience an average year. Instead, the hydrologic regime will exhibit variation from year to year (CH2M HILL 1996a).

Ewel (1990) found that hydroperiod (i.e. the duration of saturated soils or standing water) is the dominant environmental factor that controls the ecological characteristics of a swamp. Hydroperiod affects soil aeration and the ability of plants to survive and reproduce. When flooding persists, oxygen in the soil is gradually depleted, causing increasingly stressful conditions on roots. Only a few species can tolerate the lack of oxygen and high concentrations of soluble iron and manganese, and even hydrogen sulfide that develop in the root zone under these conditions. Short hydroperiods, flowing water, and high dissolved oxygen levels characterize river swamps, making organic matter removal rates rapid and fire uncommon. Generalized hydroperiods for a variety of swamp types are presented in **Table 2.**

Bald Cypress Seed Germination and Seedling Survival

Bald cypress is the most common wetland tree in Florida and is often recorded as the dominant species in swamps with fluctuating water levels. Bald cypress seeds cannot germinate when soils are flooded, although seedlings grow best in saturated but unflooded soils (Dickson & Broyer 1972), Bald cypress however grows too slowly to survive competition with faster growing hardwoods. Bald cypress does not survive extended submerged conditions (Demaree 1932), making successful regeneration of a cypress swamp highly dependent on regular water level fluctuations. When mature, however, cypress is the most flood-tolerant of all tree species in Florida (e.g. Harms et al. 1980).

Young et al. 1994 reported that bald cypress typically occurs in areas subjected to frequent or prolonged flooding. Mature trees are reported to tolerate flood depths of 3 m or more (Wilhite & Toliver 1990), but are also found in well-drained areas (Mattoon 1915). The ability of bald cypress to grow in different hydrologic regimes has been the subject of numerous studies on germination requirements (Demaree 1932, Penfound 1952, Dubarry 1963), growth of seedlings and mature trees (Mattoon 1915, 1916; Demaree 1932, Eggler 1955, Dickson & Broyer 1972, Mitsch et al. 1979), and distribution of the species (Bedinger 1971, McKnight et al. 1981, Theriot 1988). Other studies have documented the growth response of bald cypress to alterations of natural hydrologic regimes, specifically permanent inundation of an area. Results of these studies, however, have been inconsistent: Conner & Day (1976) found that growth of bald cypress in permanently flooded areas of Lac des Allemands Swamp, Louisiana, was greater than in areas with other hydrologic regimes. In contrast, Duever & McCollom (1987) found a decrease in growth of bald cypress trees in areas that had been permanently flooded in Florida. Keeland (1994) reported less growth in bald cypress trees in South Carolina that were subjected to increased flood levels relative to trees from

Table 2. Proposed hydroperiod ranges of major types of Florida swamps (based on Table 9.1 from Ewel 1990).

Type of Swamp	Average Hydroperiod*	Main Water Source
River Swamps		
Whitewater floodplain forest	Short	River
Blackwater floodplain forest	Short	River
Spring run swamp	Short	Deep groundwater
Stillwater Swamps		
Bay swamp	Long	Shallow groundwater
Cypress pond	Moderate	Shallow groundwater
Cypress savanna	Moderate	Rain
Cypress strand	Moderate	Shallow groundwater
Gum pond	Long	Shallow groundwater
Hydric hammock	Short	Deep groundwater
Lake fringe swamp	Moderate	Lake
Melaleuca swamp	Moderate	Shallow groundwater
Mixed hardwood swamp	Moderate	Shallow groundwater
Shrub bog	Long	Shallow groundwater

*Short = less than 6 months; Moderate = 6-9 months; Long = greater than 9 months

a nearby undisturbed area. A decrease in growth following deep flooding has also been reported from Illinois (Mitsch et al. 1979). A growth surge of short duration followed by a long-term depression in growth was observed by Stahle et al. (1992) in bald cypress tree that were permanently flooded following formation of Reelfoot Lake by the New Madrid earthquakes of 1811-1812.

Conner and Toliver (1990) report that in general, bald cypress regenerates well in swamps where the seedbed is moist and competitors are unable to cope with flooding, but extended dry periods are necessary for the seedlings to grow tall enough to survive future flooding. As a result, bald cypress stands are usually made up of several even-aged classes (Mattoon 1915). Naturally seeded trees often reach heights of 20-36 cm during the first growing season and 40 – 60 cm during the second season (Mattoon 1915).

Keeland and Conner (1999) reported that bald cypress seedlings die if completely submerged for a very long period during the growing season (Demaree 1932, Eggler & Moore 1961). Penfound (1949) observed that those bald cypress seedlings that barely extended above the water surface when Lake Chicot (Louisiana) was first formed were capable of surviving, while submerged seedlings were killed. Bald cypress regenerated well under low-water conditions that allowed seedlings to grow tall enough to maintain some of their foliage above the water during the growing season. Proper conditions for germination and survival include a good seed crop during the previous fall, abundant light, little competition from other species (especially mature trees), and a very moist but not flooded seedbed. Permanent flooding after establishment may slow growth rates, but seedlings taller than the maximum water-surface elevation during the growing season should have good survival. The cohort nature of bald cypress stands throughout the United States suggests that extensive regeneration of this species has historically occurred during extended periods of low water (Matoon 1915, Putnam et al. 1960).

Duever's (1980) study of the Corkscrew Swamp Sanctuary in South Florida reviewed water level data collected from four transects located along the major flowway of the Sanctuary. Results showed sites which had the largest and fastest growing bald cypress tress exhibited hydroperiods ranging from 286-296 days. Tree-ring analysis indicated that longer hydroperiods of 306-325 days at four cypress sites along the dike retarded cypress growth. Growth rates were also slower at sites with shorter hydroperiods of 133 to 270 days. Poor growth was particularly obvious on the 133-day hydroperiod site, where there was a vigorous shrub stratum of wax myrtle (*Myrica cerifera*), a species characteristic of sites with hydroperiods between 45 and 155 days.

Effects of Hydroperiod on Wetland Plant Communities

CH2M Hill (1996a) conducted a literature review on the relationship between hydroperiod and wetland type. They reported that wetlands in Florida follow natural and usually predictable fluctuations in depth and duration of inundation in response to seasonal patterns of rainfall and evapotranspiration. These fluctuations significantly influence the composition of plant and animal communities and associated wetland functions. Climatic and cultural changes in the quantity and timing of hydrologic inflows and outflows can affect the pattern and range in water level fluctuations, leading to changes in wetland structure and function.

Schomer & Drew (1982) estimated the flooding duration requirements of different Florida wetland communities by using data from a characterization of vegetation in the Florida Everglades. They found that bald cypress communities are inundated from 3 months (25% inundation) to 9 months (75% inundation) per year. Brown & Starnes (1983) defined a narrower range in average water depths and hydroperiods for the major types of wetlands in Seminole County (**Table 3**). In their assessment, bald cypress hydroperiods averaged from 250 days (68% inundation) to 300 days (82% inundation).

Table 3. Hydroperiod ranges for several wetland types (source: Brown & Starnes 1983).

Community Type	Average Low Water (ft above soil surface)	Average High Water (ft above soil surface)	Hydroperiod (days/year)
Hydric Hammock	Below ground surface	0.33	100-150
Wet Prairie	Below ground surface	1.64	150-200
Bayhead	Below ground surface	0.98	200-250
Mixed Hardwood Swamp	Below ground surface	1.97	200-250
Cypress Dome	Below ground surface	1.64	250-300
Deep Marsh	0.66	3.28	Approx. 365
Shallow Marsh	Below ground surface	2.3	Approx. 365

Table 4 provides a summary of data compiled from a number of studies conducted in central and southwest Florida. Wetland types are ranked in order of increasing hydroperiod. Average low and high water depths are provided where available. These data support the observation that wetland types are associated with a wide hydroperiod range, which generally defines the flooding tolerance of the community. The summary data also show that the hydroperiod range of a given wetland community may overlap with one to several other community types. Each of the major types can be arrayed along the hydrological gradient.

Table 4. Observed flooding depth and duration of Florida plant communities

Community Type*	Average Low Water (ft above soil surface)	Average High Water (ft above soil surface)	Hydroperiod (days/year)
Mesic Hammock			28
Low Pine Flatwoods			42-225
Wet Prairie			57
Shrub Swamp (transitional)			50-60
Cypress Dome			Approx. 105
Marsh			135-255
Oak-Palm Hammock	-1.37	1.45	75-200
Open Pine-Prairie	-1.88	1.93	150-200
Transitional Pine-Prairie	-1.98	2.03	150-200
Altered Wetlands (average)			Approx. 173
Evergreen Swamp (*Melaleuca*)			175
Scrub Cypress			194
Bay Swamp			210
Hypericum Marsh	-2.63	1.39	213
Deep Freshwater Marsh		2.63	215
Spartina bakeri Marsh	-3.21	1.26	218
Hydric Pine Flatwoods		0.56	225
Cypress/Pine Swamp			225-238
Shallow Cypress Swamp			238
Shrub Swamp (shallow)			239
Shallow Evergreen Swamp		0.47	243
Deep Cypress Swamp			250
Deeper Freshwater Marsh		0.88	254
Polygonum Marsh	-2.99	2.07	262
Fraxinus-Salix Swamp	-2.30	2.06	308
Shrub Swamp (deep)			310-350
Unaltered Wetlands (average)			Approx. 313
Cladium Marsh	-1.80	1.68	319
Cephalanthus Scrub/Shrub	-2.36	1.84	320
Panicum-Rhynchospora Marsh	-1.83	1.87	327
Pond (aquatic bed)			327-355
Mixed Emergent Marsh	-1.43	2.1	338

* Documented observed values may not reflect typical hydroperiods for some wetlands

Sources: Bays & Winchester 1986; Brown 1991; Brown & Starnes 1983; CH2M HILL 1987; CH2M HILL & Winchester 1988a, 1988b, 1988c; ESE 1991a, 1991b, 1991c, 1992a, 1992b

Floodplain Transect Survey Results

Floodplain Transect Surface Water Hydrology

Figure 2 provides a hydrograph of surface water levels recorded along each transect from 1984-1990 as well as Lainhart Dam flows for the same time period. Summary statistics (mean, standard deviation, and range of variation) were developed from these hydrographs to calculate mean differences in elevation between each transect site as compared to the Lainhart Dam. These differences in elevation are presented in **Table 5**.

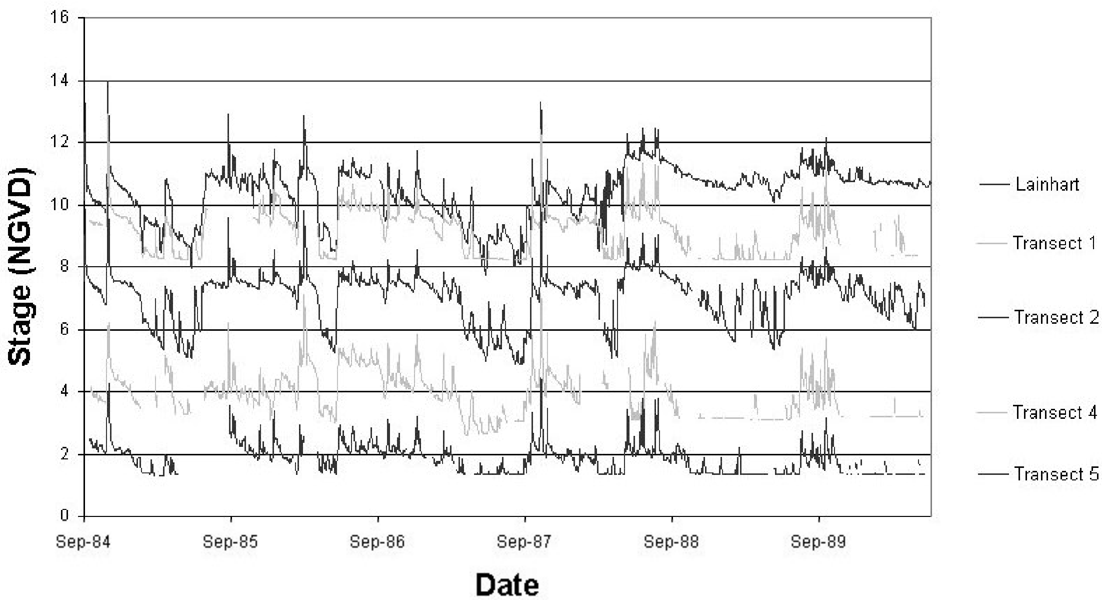


Figure 2 Daily Stage hydrographs for the four transects and Lainhart Dam (1984-1990**)**

Table 5. Mean (standard deviation) difference between the Lainhart Dam water levels and those recorded downstream at each transect location (in feet NGVD).

Transect Name	Transect 1	Transect 2	Transect 4	Transect 5
Station Id.	LOX.R1_G	LOX.R2_G	LOX.R3_G	LOX.R4_G
Mean (STD)	0.78 (0.28)	3.04 (0.37)	6.12 (0.42)	8.33 (0.38)

Floodplain Transect Soil Elevation Profiles

District staff measured soil elevations (feet NGVD) across the floodplain of the upper NW Fork of the Loxahatchee River in December 1983-April 1984 (SFWMD survey staff field notes). Elevation profiles of each transect are presented in **Figures 3a to 3d**. Results showed that average elevations of the transects decreased 6 to 7 feet in the river channel and floodplain, respectively, from Transect 1 to Transect 5 (**Table 6**). These data show that floodplain is not flat, but undulates along an elevation that varies 1.0 to 1.5 ft. from the edge of the river channel to the edge of the floodplain. Elevations of the upland – floodplain swamp ecotone between opposing sides of the river at three transects were inconsistent and highly variable. Presumably, this may be related to the magnitude of freshwater seepage available from upland areas flanking the floodplain.

Caution must be used when examining the length of transect segments as the survey did not always cross the floodplain directly perpendicular to the river channel.

Table 6. Transect Lengths and Approximate Floodplain Elevations (NGVD) at each Transect

	Transect 1	**Transect 2**	**Transect 4**	**Transect 5**
Total Transect Length (ft)	470	560	520	670
– Upland (ft)	30	90	90	20
– Floodplain Swamp (ft)	360	430	400	580
– River Channel (ft)	80	40	30	70
Floodplain-Upland Ecotone (NGVD)	12.4 – 14.6	8.0 – 11.9	4.8	2.1 – 5.6
Floodplain-Channel Ecotone (NGVD)	8.2	6.9	2.7	2.0
Channel Bottom (NGVD)	1.4	3.2	-3.2	-2.2
Mean Floodplain Elevation (NGVD)	9.9	8.2	4.0	2.3

Floodplain Hydroperiod Estimates

Table 7 shows the estimated percent of time each transect was flooded from 1987 to 2001. These hydroperiod calculations were derived from the average floodplain transect elevation measurements (ft. NGVD) shown in **Table 6,** the relationships presented in **Table 5.,** and the recorded Lainhart Dam stage data from 1987 to 2001. Results showed that hydroperiods at the four transect sites to range from 44%- 88.9% with an overall average of 72.3% (flooded an average of 264 days/year) as shown in **Table 7**. The shortest hydroperiod (driest) occurred at Transect 2 located just downstream from the Masten Dam. We believe this is caused by the proximity of the structure, which generally causes this area to be much drier than the other transect locations. In contrast, Transects 1, 3 and 4 were much wetter with average hydroperiods ranging from 76.7 to 88.9 % (flooded from 280–324 days/year). These values generally fall within ranges reported for cypress domes (250-300 days/year) but are wetter than the mixed hardwood swamp (200-250 days/year) values shown in **Tables 3** and **4**. Results of these analyses show that over the past 14 years the upstream portion of the Wild and Scenic portion of the Northwest Fork of the Loxahatchee River has experienced adequate periods of inundation to support both cypress and mixed hardwood swamp communities.

Table 7. Estimates of the Average Percent of Time each Transect was Inundated from 1987-2001

Transect	**Percent of Time Flooded (Hydroperiod)**	**Average No. of Days/year Inundated**
T1	76.7 %	280 days
T2	44 %	160 days
T4	88.9%	324 days
T5	79.8%	291 days
Avg T1,T4, T5	81.8 %	298 days
All	***72.3 %***	***264 days***

Effects of Lainhart Dam Flow Rates on Floodplain Inundation

A key question of this study was how will implementation of the proposed MFL criteria impact the portion of the river that is designated as Wild and Scenic? To answer this question, Lainhart stage and flow rate data were correlated with surface water levels and soil elevation profiles recorded at each transect, using the relationships shown in **Tables 5 and 6**. Relationships between Lainhart lows and their corresponding water depths at each transect are graphically shown in **Figures 3a to 3d** along the right-hand axis. Calculations of the percent of floodplain (excluding the river channel and upland areas) that would be flooded under a given Lainhart dam flow rate are also shown. These results are also presented in **Table 8**.

Table 8. Percent of the floodplain (area) inundated in relationship to Lainhart Dam flow rates (cfs) (excluding uplands and river channel).

Name	Lainhart Dam Flow Rates (cubic feet/second)								
	10 cfs	**25 cfs**	**35 cfs**	**48 cfs**	**65 cfs**	**75 cfs**	**100cfs**	**200cfs**	**300cfs**
Transect 1	14%*	44%	61%	61%	64%	64%	69%	78%	86%
Transect 2**	0%	7%	16%	40%	49%	53%	74%	86%	91%
Transect 4	25%	58%	75%	93%	95%	95%	100%	100%	100%
Transect 5	5%	43%	57%	71%	81%	83%	93%	98%	100%
Avg.(Transects 1, 4, and 5)	15%	48%	64%	75%	80%	81%	87%	92%	95%
Average (all transects)	11%	38%	52%	66%	72%	74%	84%	91%	94%

* Percent of the floodplain (area) inundated
** This transect is located just downstream of the Masten Dam and is influenced by this structure

From examination of the general trends shown in **Figures 3a to 3d** and **Table 8**, some general points can be made concerning the hydrology of the floodplain between SR 706 (Indiantown Rd.) and Trapper Nelson's site. Nearly all of the floodplain is inundated at flows greater than 300 cfs. Conversely, flows less than 10 cfs are required to allow surface water to fully recede from the floodplain. At flows of 35 cfs, the area of inundated floodplain ranges from 16% at Transect 2 up to 75% at Transect 4, however the average for all transects is still greater than 50% (**Table 8**).

Plots of percent floodplain inundation versus Lainhart dam flow rates at Transects 1, 4, and 5 were comparable. However, Transect 2 demonstrated a lower percent of floodplain inundated at flows under 75 cfs. Again this was attributed to the effects of the Masten Dam, which is located just upstream of this transect. It is important to note that the effects of the Masten Dam were not observed further downstream at Transect 4. Based on these data, a minimum flow of 35 cfs recorded at the Lainhart Dam would inundate more than 50% of the floodplain on average (**Table 8)**. In contrast, nearly 95% of the floodplain is inundated at a flow of 300 cfs, while flows of less than 10 cfs are needed for surface water to fully recede from the floodplain (**Table 8).**

Providing a dry season minimum flow regime that inundates more than 50% of the floodplain would provide protection from the effects of drought and over-drainage. In addition, water levels maintained within this range would also (a) provide aquatic refugia for aquatic invertebrates, amphibians and fish species to survive during dry periods, (b) reduce the possibility for invasion by melaleuca, Brazilian pepper and Old World climbing fern, and (c) reduce the frequency of severe fires that could impact the remaining floodplain swamp forest. Overall, these results indicate that the water levels resulting from a minimum flow of 35 cfs would not adversely impact the upstream floodplain swamp.

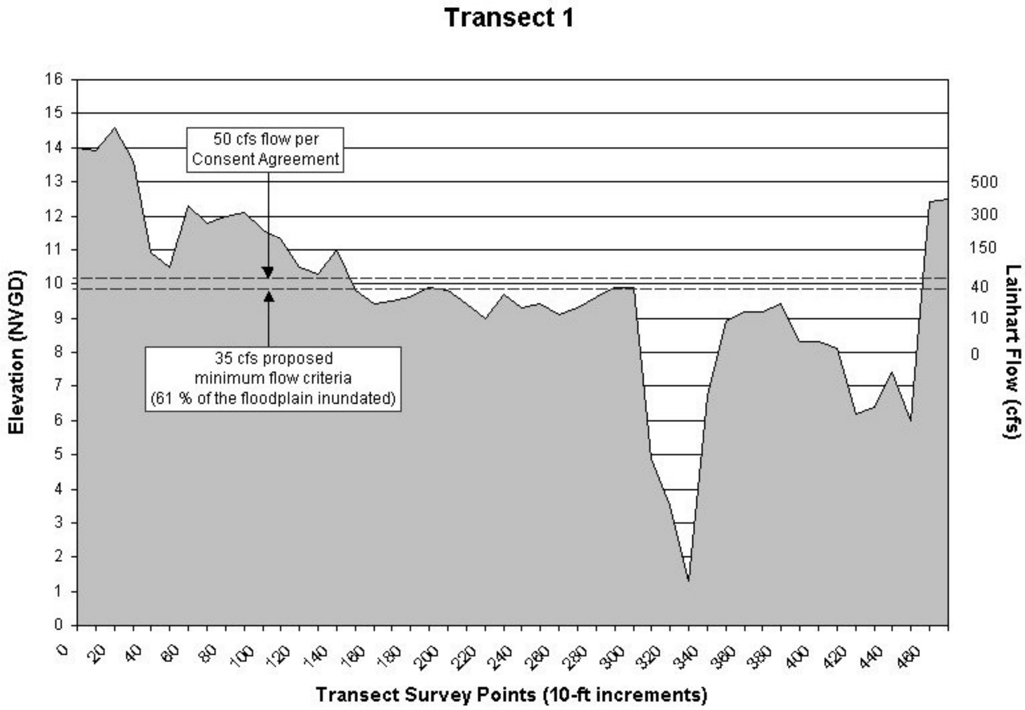


Figure 3a. Transect 1 profile across the floodplain along the upper NW Fork of the Loxahatchee River.

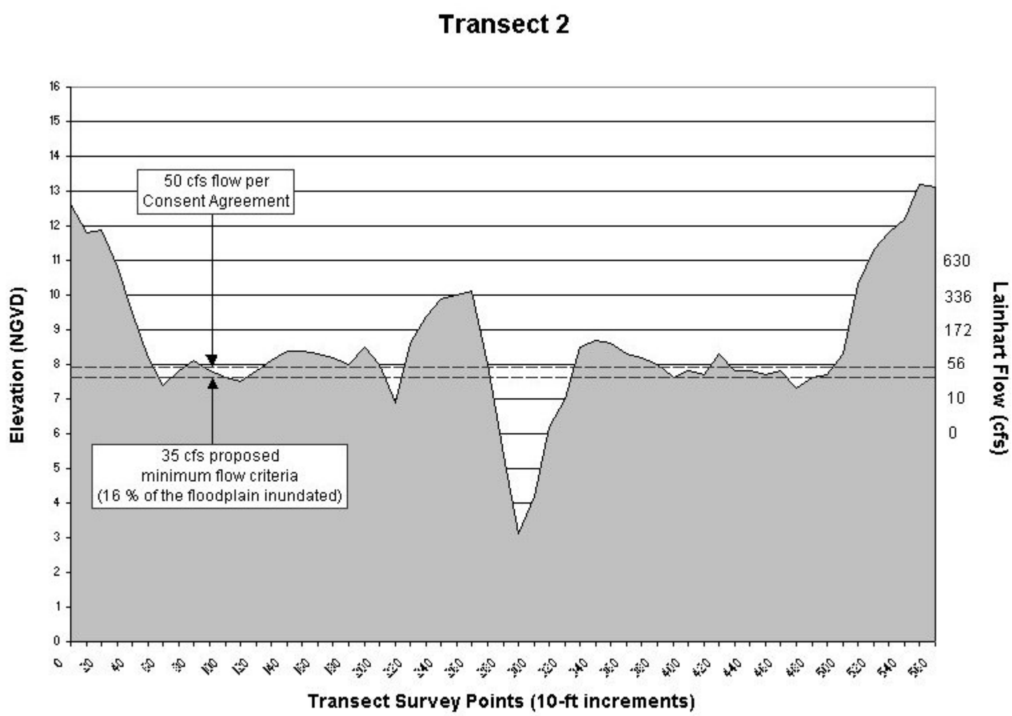


Figure 3b. Transect 2 profile across the floodplain along the upper NW Fork of the Loxahatchee River.

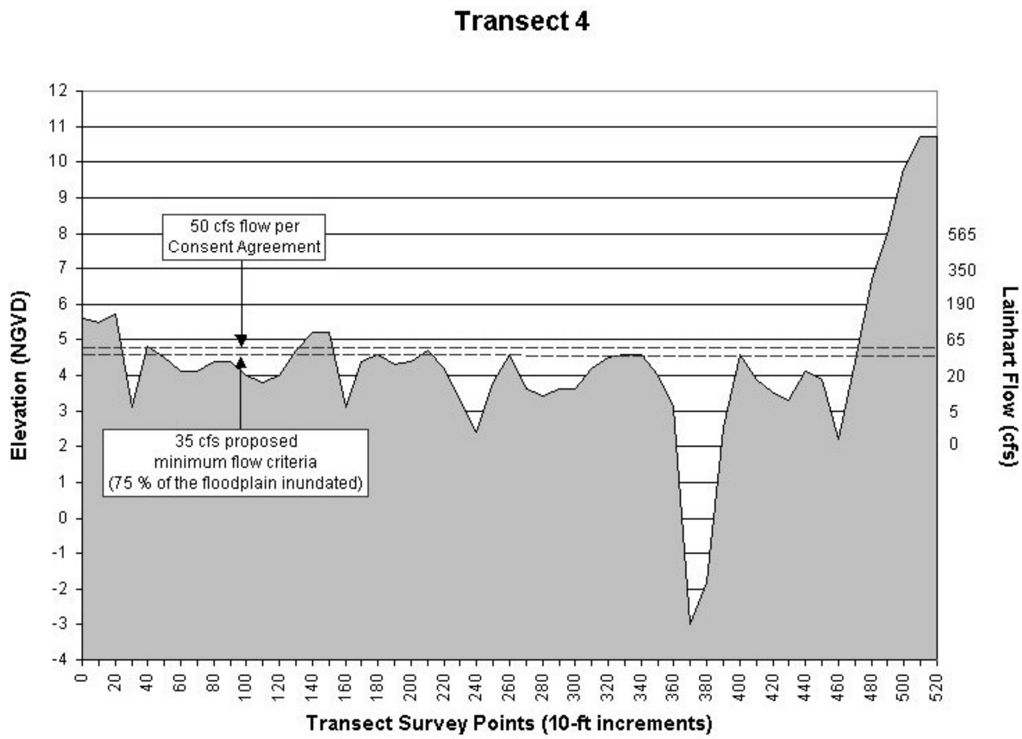


Figure 3c. Transect 4 profile across the floodplain along the upper NW Fork of the Loxahatchee River.

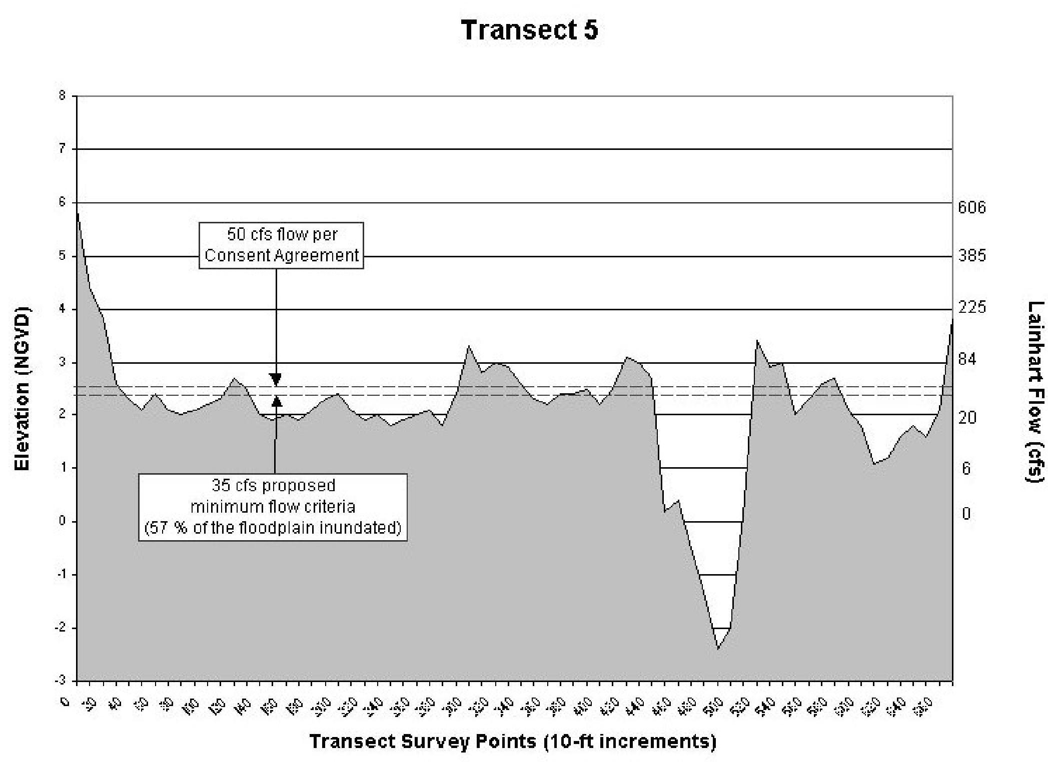


Figure 3d. Transect 5 profile across the floodplain along the upper NW Fork of the Loxahatchee River.

DISCUSSION

Hydrologic Requirements of Floodplain Communities

The analysis of stage and flow relationships at transects in the Loxahatchee River floodplain upstream of Trapper Nelson's site demonstrates how closely these two hydrological factors are linked. Since the stage at each transect is so closely correlated to stage (flow) at Lainhart Dam (see **Table 5** and **Figure 2**), flows through the river channel are a dominant factor that controls surface water levels in the floodplain (i.e., rather than groundwater or surface flows from other sources).

Establishment of a minimum flow and level for the Loxahatchee River entails determination of the lower limit that would cause significant harm to the identified resource. Elsewhere in this document, the determination of a minimum flow for the river was based on the need to protect the remaining freshwater swamp community from significant harm that occurs due to salinity intrusion. Other potential criteria (water levels) are provided in this section that should be considered when developing future floodplain management goals and objectives. Water level requirements of floodplain swamp communities have not been analyzed in sufficient detail to provide a basis to define "significant harm" to the resource.

Some possible impacts of maintaining insufficient water levels in the floodplain include: (1) increased fire frequency; (2) reduced reproduction of floodplain vegetation; (3) invasion of floodplain communities by upland or exotic species; and (4) impacts to wildlife that rely on aquatic habitats for reproduction. On the other hand, setting a minimum flow for the river that is too high, such as could occur by trying to avoid saltwater intrusion or compensate for rising sea levels, could cause (1) prolonged floodplain inundation; (2) increased scouring of the river channel and erosion of river embankments; (3) increased transport of unconsolidated material to the estuary, burying seagrass and oyster beds; and (4) drown existing floodplain swamp communities and (5) eliminate periodic dry downs required for successful reproduction. Several authors have defined an average annual duration of flooding for floodplain and bald cypress communities, realizing that "average" conditions may not occur very often. During most years, rainfall patterns are either above average or below average rainfall patterns. It is assumed that if an appropriate annual flooding duration is achieved, occasional periods of too little and too much flooding will occur due to natural variation and that extreme conditions are also a part of the natural system.

Future efforts to establish restoration targets for the river will include consideration of the whole range of variability required to sustain a healthy floodplain swamp community. The focus of the MFL, however, is to examine water flows and levels that are required to prevent significant harm. In order to address the latter issue, we first determined the amount of flow needed to protect the river floodplain community from significant harm due to saltwater intrusion. During the course of this analysis, the peer review panel asked the question: What are the effects of the proposed MFL criteria on the upstream wild and scenic portion of the river? This appendix provides one approach to analyzing these effects. We have not studied this issue in sufficient detail, however, to develop a quantitative relationship between water levels and significant harm to the resource. Such an analysis would be needed to establish “minimum level” criteria for the Loxahatchee River floodplain. To describe the effects of water levels on the floodplain, we first examined the water level requirements of soils and different plant communities that occur along the NW Fork of the river. Each of these requirements was determined individually with no expectation that one would necessarily be consistent with one another.

Water Level Requirements of Floodplain Soils

Water levels should rarely fall to the point where the floodplain soils dry out and are subject to desiccation. A review of transect elevations (see **Figures 3a to 3d**, **Table 7**) indicates that flows of approximately 5 cfs and lower (except at Transect 2, which is influenced by Masten Dam) are required to lower surface water levels in the river channel to more than 1 ft. below the soil surface. Altough a 1 ft criteria was used as a performance measure for protection of peat soils in the Everglades (SFWMD 2000), such a criterion would be very conservative for the Loxahatchee River floodplain, since the soils in this area are predominantly mineral alluvial deposits (sand) as opposed to organic (peat) in composition. It is recommended, therefore, that protecting soils from the effects of excessive drying is not a critical resource protection issue in the Loxahatchee River floodplain.

Summary of Hydroperiod Requirements for Floodplain Swamps

Based on the studies cited above, District staff have summarized the findings of the literature review to provide appropriate ranges of flooding and drying (hydroperiod) that will support and sustain both bald cypress and mixed hardwood swamp species. These data are summarized in **Table 9** below which reports average annual hydroperiods for floodplain swamp, bald cypress, and mixed hardwood communities from a variety of habitats.

Key findings of this review indicate that the floodplain swamp, community is inundated on average, 120 days/year, with a range from 30 to 183 days reported from the literature **(Table 9).** These hydroperiod values are considerably shorter than those reported for bald cypress and mixed hardwood swamps, but there is some overlap in the ranges. The hydroperiod range for a typical bald cypress swamp varied from 133 to 330 days/year, with an average of approximately 240 days/year (see Duever 1980, CH2M HILL 1996a). At the lower end of this range, poor growth was reported and a vigorous shrub stratum of drier habitat species was found. At the upper end of this range, growth rates were reduced, as open water habitats tended to occupy sites with hydroperiods longer than 330 days. Average hydroperiods reported for typical mixed hardwood swamp range from 150-240 days/year (**Table 9**).

Results of this study showed that the upstream floodplain of the wild and scenic portion of the river is inundated from 160 days/year (Transect 2) to 324 days/year (Transect 4). Overall, the four transects were flooded 264 days/year (flooded 72.3% of the time), on average (**Table 7).**

Table 9. Average annual hydroperiod of floodplain, bald cypress, and mixed hardwood swamp communities. Results represent study sites from Florida.

Community Type	Hydroperiod(days/year)	Author(s)
Floodplain Swamps		
Typical	30-150 (120 average)	CH2M HILL 1996a
	60-135	ESE 1994
Whitewater	less than 183	Ewel 1990
Blackwater	less than 183	Ewel 1990
Bald Cypress		
"Slow-growing"	133-270	Duever 1980
"Fast-growing"	286-296	Duever 1980
"Slow-growing"	306-325	Duever 1980
Cypress Communities		
Deep	250	CH2M HILL 1996a*
	270-330 (300 average)	CH2M HILL 1996a
Dome	250-300	Brown & Starnes 1983
	Approx. 105	CH2M HILL 1996a*
Pond	183-274	Ewel 1990
Savanna	183-274	Ewel 1990
Strand	183-274	Ewel 1990
Shallow	90-180 (150 average)	CH2M HILL 1996a
	238	CH2M HILL 1996a*
Typical	180-270 (240 average)	CH2M HILL 1996a
	80-260	Shomer & Drew 1982
Mixed Hardwood		
Typical	183-274	Ewel 1990
	200-250	Brown & Starnes 1983
	90-180 (150 average)	CH2M HILL 1996a
	90-180	ESE 1994
Deep	180-270 (240 average)	CH2M HILL 1996a

*Results represent a summarization of findings from multiple authors

Some general conclusions can be drawn from this review. First, fluctuating water levels with an occasional draw down are essential components of the life cycle of floodplain, bald cypress, and mixed hardwood swamp communities. Forested wetland communities that do not periodically dry out and thus are inundated most of the year do not support seedling reproduction or sustainable growth of swamp vegetation. Swamps that have been altered by dams, levees or roads, which caused unnaturally prolonged hydroperiods, have experienced stress and eventual death of forest vegetation (see Keeland & Conner 1999, Young et al. 1994). The literature review indicates that no natural, healthy, or reproductive floodplain swamps are found on sites with hydroperiods in excess of an average of 330 days/year (inundated 90% of the time). Furthermore, excessively long hydroperiods will suppress seed germination and seedling growth (Keeland & Conner 1999, Mattoon 1915, Keeland et al. 1996, Conner & Toliver 1990, Ewel 1990). In contrast, hydroperiods that are too short (less than 130 days/years or 35% inundation) result in a shift to vegetation typically found in short-hydroperiod, drier wetland communities.

Examination of the survey transects from the upper NW Fork shows that surface water is essentially confined to the river channel when flows are less than 10 cfs, indicating that very low flows are required to fully draw down surface water from the floodplain swamp. On the other hand, flows greater than 300 cfs are required to fully inundate the floodplain swamp (i.e. surface water covers more than 90% of the floodplain). Water depths can exceed 2.5 ft under these conditions. Therefore, in order to provide the required draw down for the floodplain swamp, surface water levels should occasionally fall to a level that dries out most of the floodplain. These low water conditions correspond to flows of less than 25 cfs (see **Table 8**) and are essential to avoid flooding stress, promote seed germination, and allow sufficient time to establish swamp tree seedlings and regenerate the forest. Based on the long-term rainfall trends reported in **Figure 4** of the Technical Document, it is estimated that such extreme drought conditions occur within the basin approximately once every 9 years on average.

Water Level Requirements of Fish & Invertebrates

The Southwest Florida Water Management District (SWFWMD) initiated an analysis of the minimum flows and levels for the Upper Peace River (SWFWMD 2002). As part of their studies and criteria, they examined the effects of low water levels on fish habitat and passage. The SWFWMD reasoned that maintaining depths of 0.6 ft or greater would provide adequate water levels for fish passage and would also ensure continuous flow, allow for recreational navigation (e.g. canoeing), improve aesthetics, and avoid or lessen other potential problems related to no flow conditions, such as low dissolved oxygen concentrations, localized phytoplankton blooms, and increased predatory pressure resulting from loss of habitat/cover. Extreme conditions, such as drying of the river channel, have not been reported from the upper NW Fork of the Loxahatchee River. However some of the concerns of fish passage, recreational navigation, and water quality may merit consideration during development of futures restoration plans for the Loxahatchee River. A review of the historic water levels for the upstream segment of the NW Fork (**Figures 4a to 4d**) indicates that water levels in the channel have not declined to less than one foot during the period of record (1971 to 2002), even when no flow over Laonhart Dam was recorded. The minimum flow of 35 cfs, which is proposed to prevent saltwater intrusion in the upstream segment of the NW Fork, provides sufficient water depths and flows to meet these needs.

The "wetted perimeter inflection point" technique used by the Southwest Florida Water Management District on the Upper Peace River minimum flow and level project (SWFWMD 2002) was reviewed for application to the Loxahatchee River. Wetted perimeter methods assume that a direct relationship exists between wetter perimeter and fish habitats in streams (Annear & Conder 1984). Studies on streams in the Southeast (Benke et al. 1995) have demonstrated that the greatest amount of macroinvertebrate biomass per unit reach of stream occurs on the stream bottom. This aquatic habitat type is primarily that of bedrock or unconsolidated sand bottom, which is different from that normally found within the floodplain itself. **Table 10** shows water elevation and flow at which the entire river channel is inundated. A review of this information shows that a flow of more than 25 cfs would provide maximized wetted perimeter of the stream bed, except at Transect 2 where the downstream effects of Masten Dam have changed the floodplain hydrology.

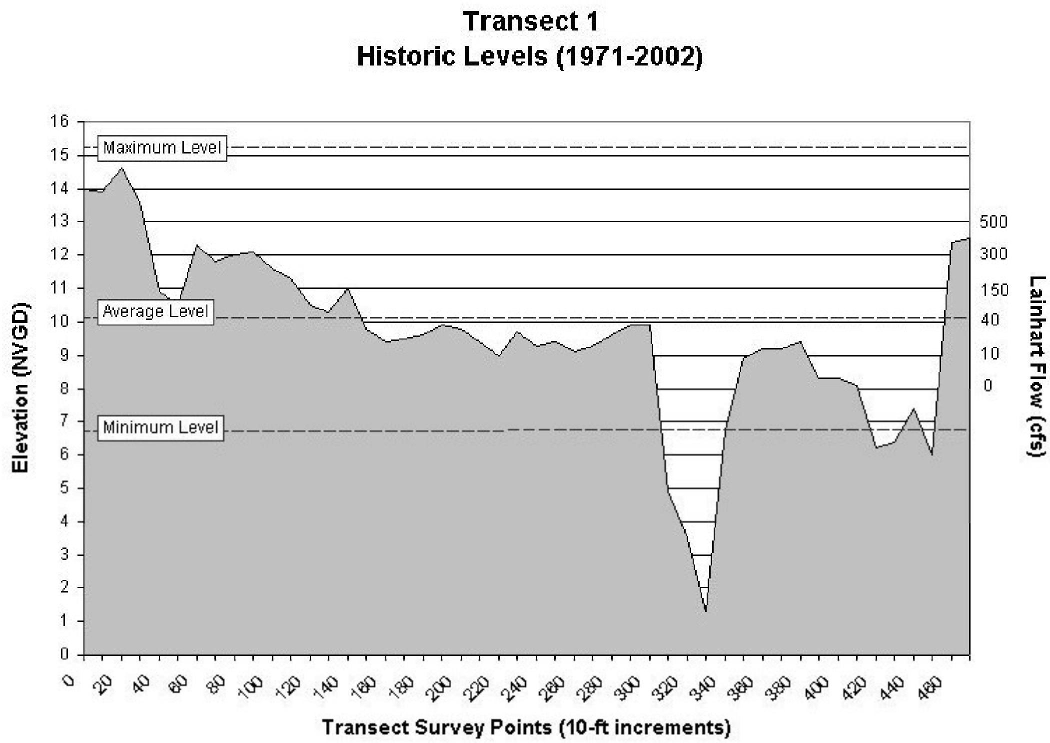


Figure 4a. Historic water levels at Transect 1.

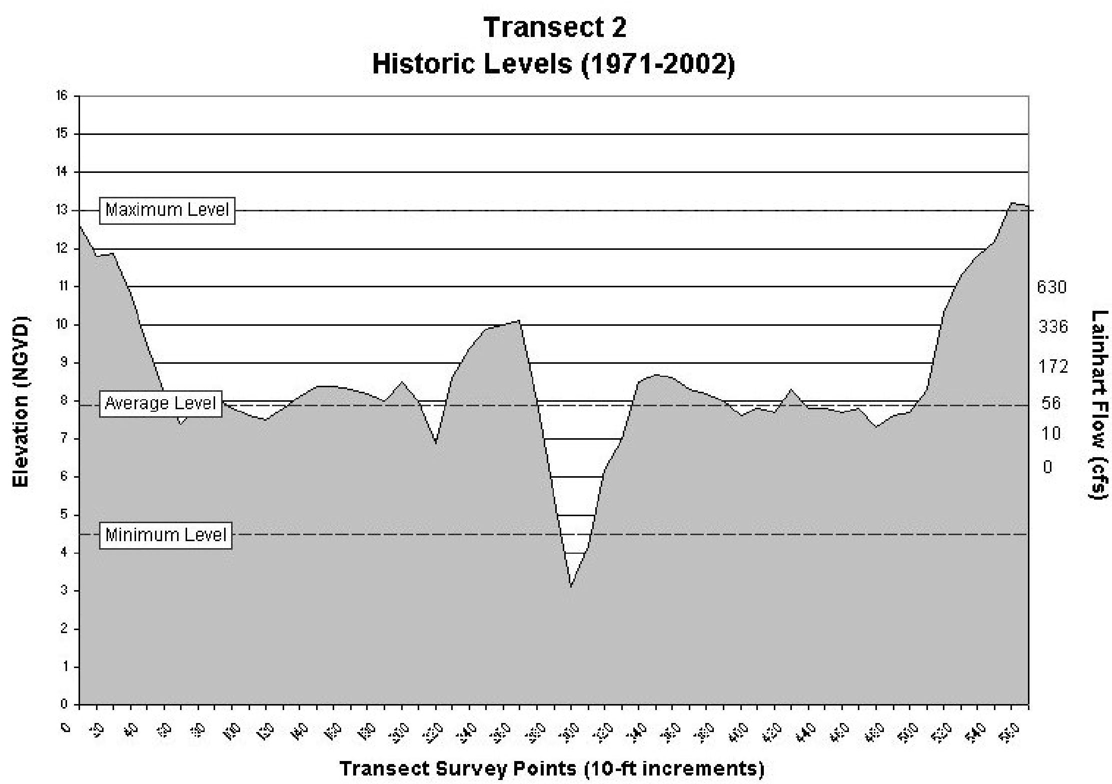


Figure 4b. Historic water levels at Transect 2.

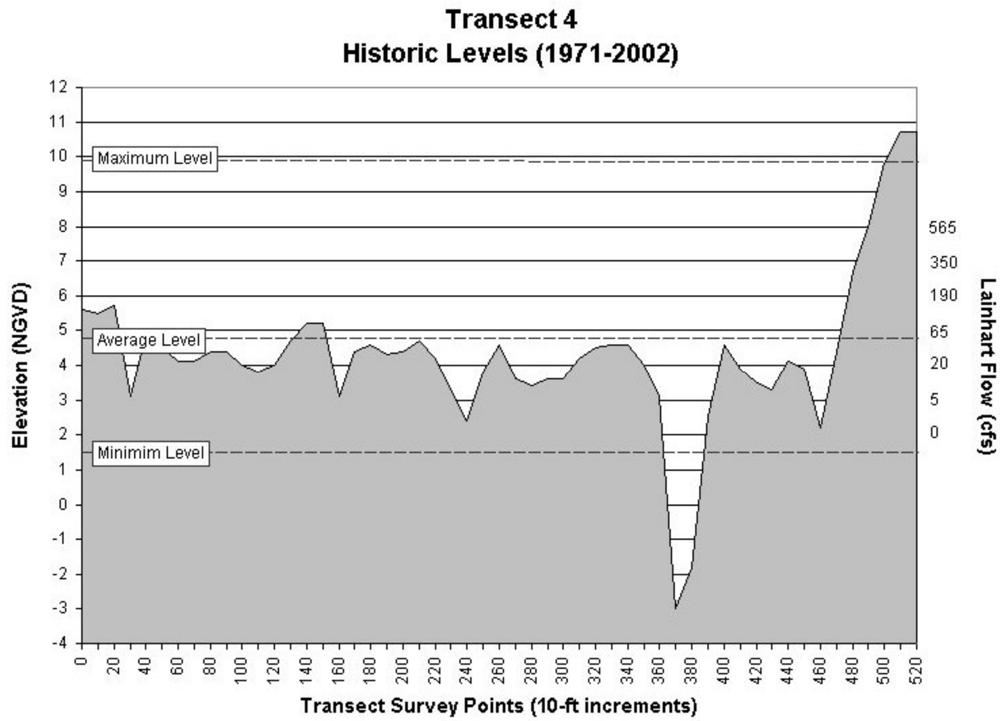


Figure 4c. Historic water levels at Transect 4.

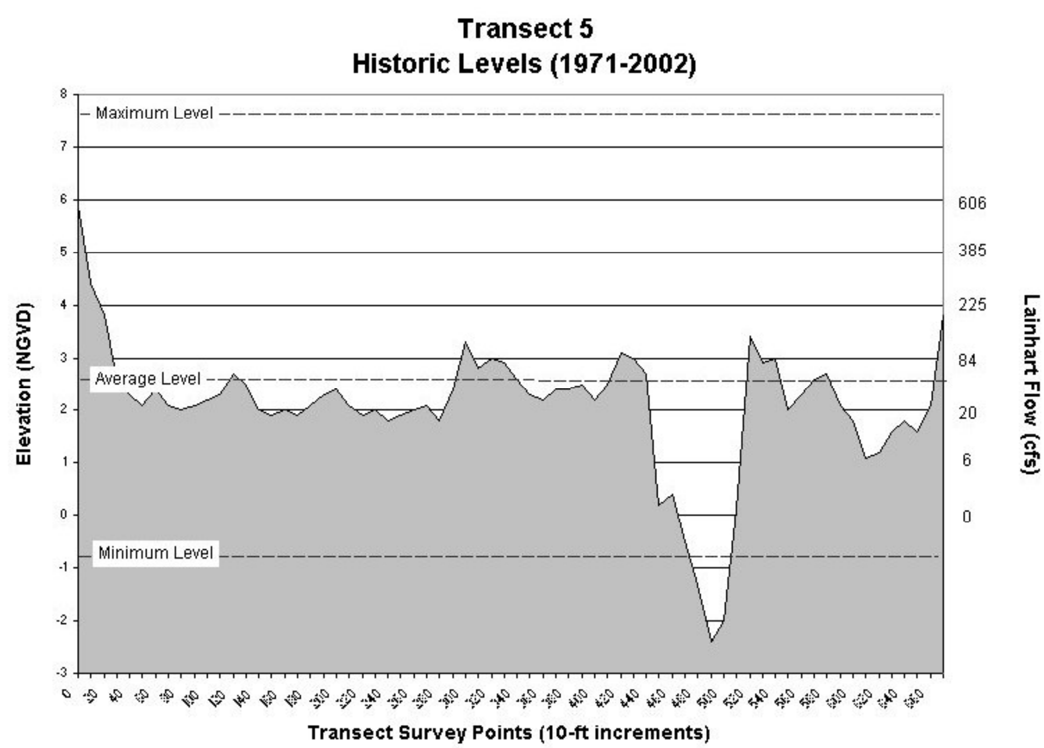


Figure 4d. Historic water levels at Transect 5**.**

Table 10. Surface water levels and respective flows required to fully inundate the stream channel and bottom of the upper NW Fork of the Loxahatchee.

Transect	Approximate Elevation (NGVD)	Approximate Flow at Lainhart Dam (cfs)
T1	9.0	10
T2	7.9	48
T4	4.0	15
T5	2.2	28
Avg (T1, T4, and T5)*		18
Avg (All Transects)		25

* Transect 2 is Located just south of the Masten Dam and heavily influenced by it, an average of the transects not affected by this factor is included.

Summary of Water Level Criteria for Floodplain Communities

Table 11 presents a summary of water level criteria for floodplain communities (outlined above). Results from analysis of floodplain elevation, flooding characteristics, and historical water level data indicate that the proposed MFL criterion for the NW Fork is within recommended ecological targets for soils and floodplain vegetation. Caution must be exercised when setting a minimum flow and level for the NW Fork that will remove the potential for periodic natural draw down of surface water levels in the floodplain swamp. Artificially high minimum flows, intended to stave off salinity intrusion resulting from dredging and opening of the Jupiter Inlet, may prolong hydroperiods and drown upstream portions of the floodplain swamp in the upper reaches of the river, and inhibit germination and growth of seedlings that regenerate the forest.

Table 11. A Summary of Water Level Requirements for the Upper NW Fork of the Loxahatchee River

Parameter	Purpose	Flow*	Level	Minimum Duration
Floodplain soils	Prevent desiccation of soil and degradation of organic soils	Greater than 5 cfs	Groundwater not to fall more than 1 ft below soil surface	
Floodplain Vegetation	Prevent damage to floodplain vegetation from excessive flooding and allow sufficient time for seedling establishment	Less than 25 cfs	Surface water covers less than approximately 1/3 of floodplain	60-240 days/year
Water Quality	Prevent stagnation of stream water and reduce saltwater intrusion	35 cfs or more		
Wetted Perimeter	Maximize the extent of stream habitat	Greater than 25 cfs	Stream bed and banks inundated	

*expressed as cubic feet per second flow over Lainhart Dam

It is important to note that this analysis focuses on the upper NW Fork of the Loxahatchee River, defined as that segment between Trapper Nelson's site and Indiantown Rd. (SR 706). Historically, this portion of the river seems to have periodically experienced very low flows and water levelsthat were necessary for seed germination and seedling survival of cypress and other freshwater swamp species.. Flows from other downstream tributary sources (e.g., Cypress Creek, Hobe Grove Ditch, or Kitching Creek) may need to be increased as a means to control saltwater intrusion within the river while periodically reducing flows along the upper NW Fork of the river to allow drying of the floodplain for seed germination and regrowth.

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